# Science with the Kepler Mission

Thomas N. Gautier

JPL Kepler Project Scientist

Jet Propulsion Laboratory, California Institute of Technology

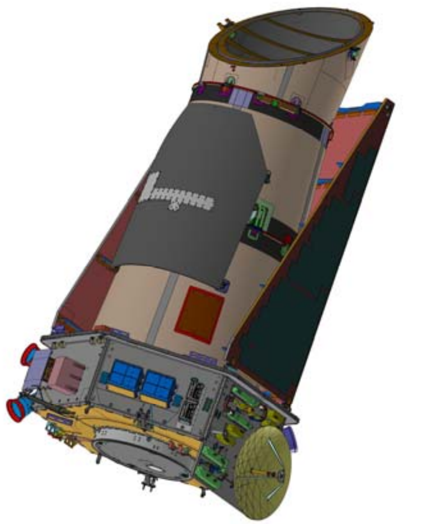
# The Kepler Mission

- Kepler is designed to take a census of planets around solar-like dwarf stars.
  - Uses the transit method to detect planets
  - Sensitive enough to see an earth-size planet in a 1 year orbit around a G2V star
  - Lifetime long enough to detect long period planets
    - Earth-size planets with periods from ~10 days to 1 year
    - Giant planets with periods from a few days to 1.3 years

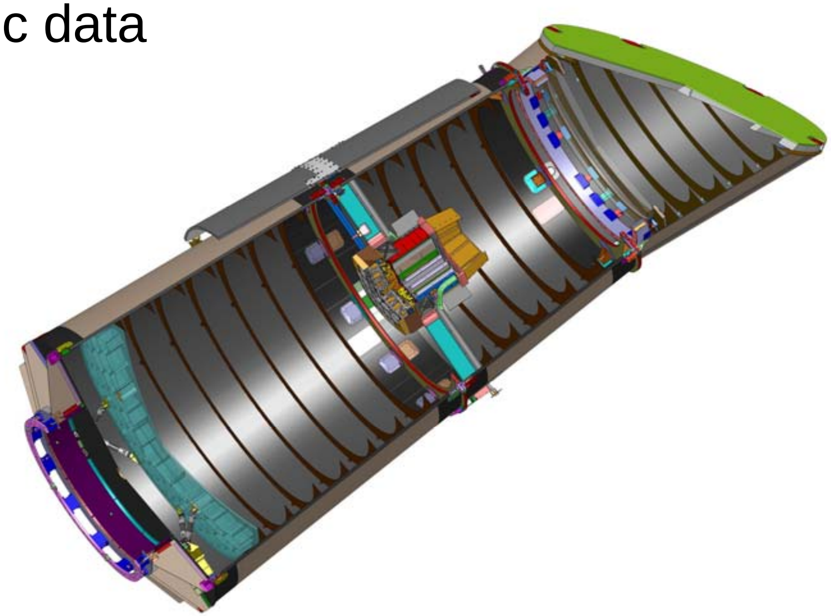
- Kepler will also characterize the detected planetary systems by combining ground based follow-up observations with its space based data
  - Measure masses and densities of detected planets when possible
  - Look for non-transiting members of the planetary systems
  - Provide detailed knowledge of the parent stars of detected planets

# Photometer description

- 95 cm aperture Schmidt camera
- 95 Mpixel CCD focal plane
  - ~115 $deg^2$ field of view, 4 arcsec pixels
- Single color, 400 - 850 nm passband
- Records time series of small groups of pixels around each target for photometric data



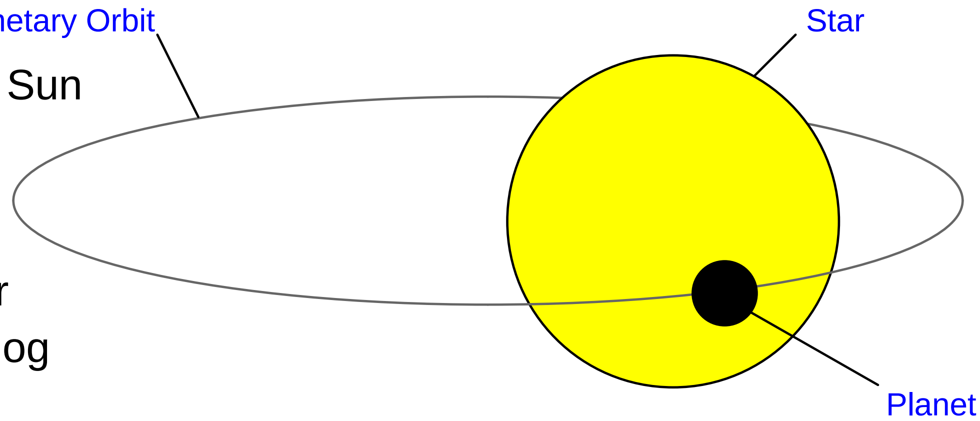
- 170,000 simultaneous targets with 30 minute integrations and
- 512 simultaneous targets with 1 minute integrations
- Can store up to 2 months of data



# Mission description

- Orbit: heliocentric, Earth trailing
  - Need space environment away from Earth for stability and constant viewing
  - Separates from Earth at ~0.1 AU/yr
- Lifetime: nominal 3.5 yr, extendable to ~6 years
- Launch Date: February 2009
- Field of view location and spacecraft configuration allow uninterrupted viewing for ~3 months at a time
  - Must roll spacecraft 90° once per quarter to maintain proper orientation with the Sun
  - Additionally must interrupt data collection for ~12 hr monthly to return data to ground
- The Jet Propulsion Laboratory manages the development of Kepler. After launch and commissioning NASA Ames Research Center will manage and operate Kepler. Ball Aerospace and Technologies Corp. is designing and building the Kepler flight system.

# Kepler Sensitivity

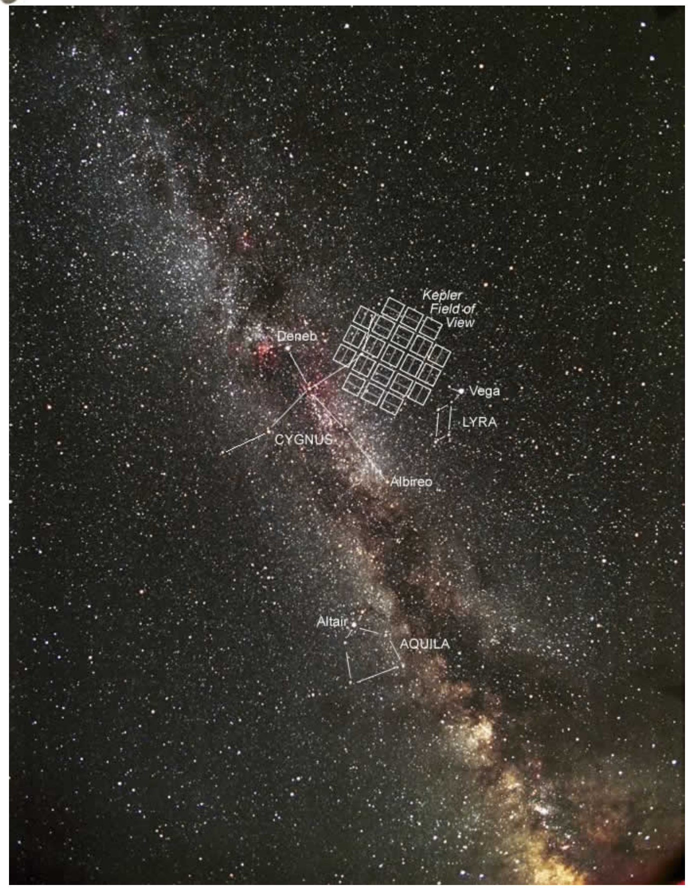


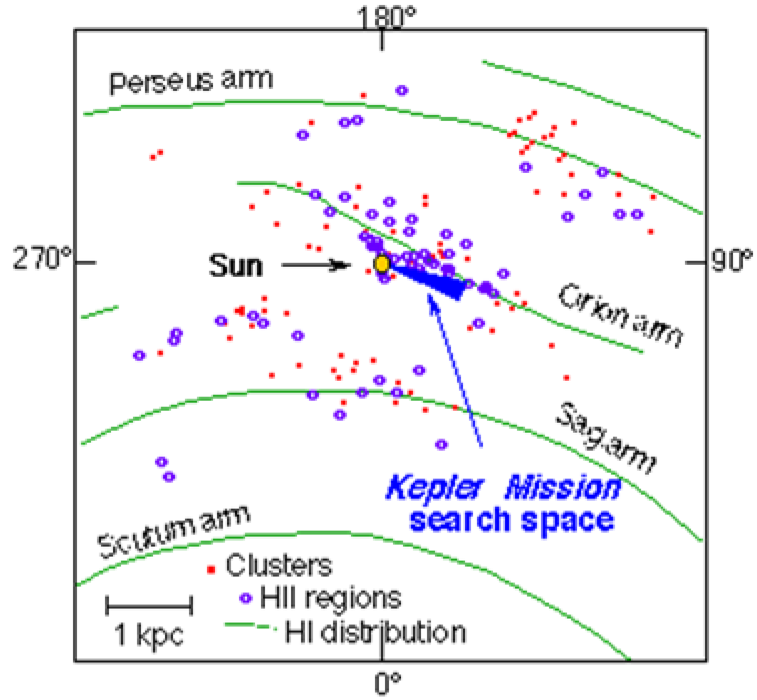

- Photometric sensitivity
  - Transit depth of Jupiter across the Sun is 1%
  - Transit of Earth is .008%
  - Kepler is designed for .002%, 1$\sigma$ sensitivity on an $m_v$=12 G type star
  - Transit of 12$^{th}$ mag Earth-Sun analog gives > 4$\sigma$ single transit SNR
  - Require 7$\sigma$ total SNR
    - 4 transits for Earth-Sun analog
    - Planets smaller than Earth can be seen if period is short or star is small
    - Giant planets need only 3 transits
- Geometric sensitivity
  - Probability of a circular planetary orbit lining up to produce a transit for Kepler is $R_{star}/a_{planet}$
  - 0.5% for an Earth-Sun analog system
  - 5.5% for a 10 day orbit around a G2V star
  - Probability $\propto R_{star}\, M_{star}^{-1/3}\, p^{-2/3}$

# The Kepler Experiment

- Monitor a large number of stars continuously for several orbital periods with high photometric sensitivity
- Select dwarf stars in with spectral types F0 to M5 and brightness  mv = 9 - 16
  - Target stars must be small enough and quiet enough to produce detectable transits of earth-size planets
- Initially monitor ~170,000 stars with 30 minute sampling cadence
  - 30 min sampling is good enough for expected transit durations of 3 - 13 hr
  - Down select to ~100,000 quietest stars if necessary to accommodate slower data transmission capabilities late in the mission
- Collect continuous photometric time series for 3.5 years
  - 3.5 year lifetime allows ~50% of 1 year period planets to display 4 transits
  - Extension of mission to 6 years would allow detection of terrestrial planets with periods up to 2.5 years
  - Spacecraft design constraints require short breaks in data collection
    - ~12 hr break each month, ~24 hr break each quarter
- Monitor 512 stars at a time with 1 min sampling cadence
  - Asteroseismology
  - Detailed examination of transit entry and exit for high SNR transits
- Follow up transit candidates with ground based observations to eliminate false positive planet indications and to characterize confirmed planetary systems

# Kepler Field of View




- FOV selected to provide sufficient star density and continuous visibility
- Kepler will generally target stars with spectral types F0 to M5 and $m_v = 9 - 16$
- Most Kepler stars will be between 50 pc and 800 pc away
  - Late Ms might be as close as 5 pc

# Kepler Target Stars

Total stars monitored 100000

Number of available stars

| Sp Type | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | total/SpT |
|---|---|---|---|---|---|---|---|---|---|
| | | | | R magnitude | | | | | |
| A5 | 34 | 141 | 428 | 1248 | 2729 | 5604 | 9735 | 15825 | 35744 |
| F0 | 32 | 143 | 434 | 1435 | 3896 | 8942 | 17977 | 31142 | 64001 |
| F5 | 47 | 164 | 555 | 2043 | 6342 | 19112 | 51584 | 121317 | 201164 |
| G0 | 38 | 161 | 597 | 2001 | 7161 | 24835 | 80396 | 234631 | 349820 |
| G5 | 15 | 76 | 248 | 815 | 3210 | 10652 | 34705 | 105232 | 154953 |
| K0 | 7 | 32 | 158 | 556 | 2026 | 6789 | 23320 | 73855 | 106743 |
| K5 | 2 | 19 | 80 | 283 | 1050 | 3860 | 13081 | 44209 | 62584 |
| M0 | 1 | 1 | 12 | 37 | 159 | 648 | 2490 | 8806 | 12154 |
| M5 | 0 | 0 | 1 | 8 | 29 | 98 | 480 | 1765 | 2381 |
| total | 176 | 737 | 2513 | 8426 | 26602 | 80540 | 233768 | 636782 | 989544 |

Number of target stars

Minimum detection threshold 1 Aearth planet

Minimum detection threshold 2 Aearth planet

Minimum detection threshold 4 Aearth planet

| Sp Type | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | total/SpT |
|---|---|---|---|---|---|---|---|---|---|
| | | | | R magnitude | | | | | |
| F0 | 32 | 143 | 434 | 1435 | | | | | 2044 |
| F5 | 47 | 164 | 555 | 2043 | 6342 | | | | 9151 |
| G0 | 38 | 161 | 597 | 2001 | 7161 | 21353 | | | 31311 |
| G5 | 15 | 76 | 248 | 815 | 3210 | 10652 | | | 15016 |
| K0 | 7 | 32 | 158 | 556 | 2026 | 6789 | | | 9568 |
| K5 | 2 | 19 | 80 | 283 | 1050 | 3860 | 13081 | | 18375 |
| M0 | 1 | 1 | 12 | 37 | 159 | 648 | 2490 | 8806 | 12154 |
| M5 | 0 | 0 | 1 | 8 | 29 | 98 | 480 | 1765 | 2381 |
| total | 142 | 596 | 2085 | 7178 | 19977 | 43400 | 16051 | 10571 | 100000 |

- A representative distribution of 100,000 Kepler target stars based on the Becanson model
- The actual distribution of 170,000 stars is being developed based on a photometric survey of the Kepler field

# Expected Survey Results and Core Kepler Science

- A few hundred to a few thousand terrestrial planets
  - Depends on the actual abundance of planets
  - Get planetary size and distance from star from period and transit depth
  - Measure masses and densities of a few planets in short period orbits around low mass stars with high precision radial velocity
- 200 - 600 transiting giant planets and some number of short period giant planets seen in reflected light
  - Get planetary size and distance from star from period and transit depth
  - Measure masses of a few examples. Get densities for transiting giants.
  - Get albedos for transiting planets also seen in reflected light
- Follow up stars with transiting planets with long term radial velocity monitoring to search for non-transiting planets in the system
- Asteroseismic analysis of bright Kepler stars to determine stellar characteristics of age, mass and size.
- Astrometric distances of most Kepler targets.

# Other Possible Science with Kepler

- Analyze giant planet atmospheres with reflected light data
- Use transit timing measurements to search for non-transiting planets
- Measure rotation rates of stars with detectable star spots
- Study stellar surface features such as star spots and granulation
- Look for stellar cycles similar to the Sun's solar cycle
- Eclipsing binary studies, including discovery of extreme mass ratio binaries
- Investigate relationship of binarity to planet existence
- Investigate variability in external galaxies on a wide range of time scales
- Anything else enabled by precision long term photometry of objects in the Kepler field of view.

# Opportunities for participation

- Participating Scientist Program
  - Eight proposals have been selected for scientists to work closely with the Kepler team to develop additional analysis methods for the Kepler data and perform investigations beyond the core Kepler science.
  - See http://nspires.nasaprs.com/external/ for details of the selected proposals
- Guest Observer Program
  - Guest observers may propose to select targets in the Kepler field for collection of time series data
  - Proposals due before launch
  - 3025 targets available at any one time
  - Changeable quarterly
- Data Analysis Program
  - Community scientists may apply to engage in data mining of the Kepler data base of ~170,000 time series up to 3.5 years long.
  - Data available after analysis for planetary transits
  - Proposals due after launch

- More information at http://kepler.nasa.gov/

# Kepler Science Team

William Borucki
Principal Investigator
NASA Ames Research Center

Gibor Basri
University of California-Berkeley

Natalie Batalha
San Jose State University

Alan Boss
Carnegie Institute of Washington

Donald Brownlee
University Of Washington

Timothy Brown
Las Cumbres Observatory
Global Telescope (LCOGT)

Doug Caldwell
SETI Institute

John J. Caldwell
York University, Toronto

William Cochran
McDonald Observatory

Jørgen Christensen-Dalsgaard
Aarhus University, Denmark

Edna DeVore
SETI Institute

Edward (Ted) Dunham
Lowell Observatory

Andrea Dupree
Harvard Smithsonian CfA

Thomas Gautier
Jet Propulsion Laboratory

John Geary
Harvard Smithsonian CfA

Ronald Gilliland
Space Telescope Science Institute

Alan Gould
Lawrence Hall of Science
University of California

Steve Howell
Planetary Science Institute

Jon Jenkins
SETI Institute

David Koch
NASA Ames Research Center

Yoji Kondo
NASA GSFC

David Latham
Harvard Smithsonian CfA

Jack Lissauer
NASA Ames Research Center

Geoff Marcy
University of California-Berkeley

Dave Monet
US Naval Observatory

David Morrison
NASA Ames Research Center

Tobias Owen
University of Hawaii

Harold Reitsema
Ball Aerospace & Technologies Corp.

Dimitar Sasselov
Harvard-Smithsonian CfA

Jill Tarter
SETI Institute